3b
NH
810
B35
1900

ography Bookshelf,
No. 5.

1/- net.

PHOTOGRAPHY IN COLOURS.

By R. CHILD BAYLEY, F.R.P.S.

LONDON:
ILIFFE, SONS & STURMEY LTD.
1900.

THE GETTY CENTER LIBRARY

PHOTOGRAPHY IN COLOURS.

PHOTOGRAPHY

IN

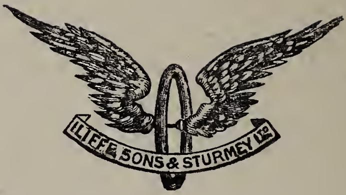
COLOURS

BY

R. CHILD BAYLEY, F.R.P.S.

LONDON:
ILIFFE, SONS & STURMEY LIMITED.
1900.

Cons.
NH
810
B35
1900



THE GETTY CENTER
LIBRARY

CONTENTS.

PAGE

1.—The Nature of Colour 9

2.—The Undulatory Theory of Light ... 14

3.—The Lippmann Process 19

4.—The principles of Colour Vision ... 26

5.—The Ives Processes 30

6.—The Joly Process 37

7.—Coloured Lights and Pigment Colours ... 43

8.—Three-colour Lantern Slides 49

9.—The Diffraction Grating Process ... 55

10.—Three-colour Photo-mechanical Prints ... 65

11.—Other Three-colour Processes 70

12.—Conclusion 72

THIS little book took its origin in a series of editorial articles in *Photography*, of which it is in the main a revised reprint. The author has kept one aim in view throughout, viz., to put before those who are familiar with the ordinary processes—the average professional and amateur photographer in fact, who wishes to know what is doing in colour work without plunging into its practice—just such an outline of the various methods by which it is accomplished as is necessary to form a correct idea of its principles. Technicalities have as far as possible been omitted or explained, so that there should be little or nothing to prevent it being understood and followed by any reader: even by one without the slightest acquaintance with photography, and few must now be in that condition.

PHOTOGRAPHY IN COLOURS.

1.—*The Nature of Colour.*

Those who read the daily papers—and nearly everybody does that nowadays—will be quite well aware that photography in natural colours has been an accomplished fact for a good many years. Like much else that is to be found in the non-technical papers, this information is to the lay mind grossly misleading; to the practical photographer, who knows what has been done, it is of course not information.

Photography in natural colours, as far as such phrase conveys any meaning to the outsider, is as far off achievement now as it ever was. The purpose of this work is to give a short outline of the various means of obtaining something to which the name photography in natural colours may be applied, with a certain amount of qualification; although it is as well to point out at once that the processes can only be regarded as either beautiful scientific experiments, or as clever makeshifts.

The expression photography in colours naturally leads one to think of the question of colour, as if the actual meaning of the word colour is not really grasped the expression can remain but an empty phrase. We will therefore consider what we mean by colour before passing to the methods by which it is attempted photographically to reproduce it.

Probably everyone in these times is well aware that when they perceive a coloured object, that object is visible and appears coloured because it transmits coloured rays of light to their eyes. The object cannot be seen as coloured unless it either gives off coloured light of itself or reflects coloured light which has already fallen upon it.

All the beautiful colours of nature, with very few exceptions, are derived directly from the sunlight which has fallen upon the various objects, and has been reflected back to the eye.

Now, that being so, it is clear that all those colours must be contained in sunlight, although in the ordinary way it is white. If the sunlight is allowed to pass through an instrument called a spectroscope, the fact that this white light is really composed of coloured light is at once shown.

The beam of white light which passes into the instrument has become spread out, when it emerges, into a broad band in which it is easy to distinguish the colours—red, orange, yellow, green, blue, and violet. The spectroscope does for light what the chemist does for substance when he analyses it or splits it up into its component parts and shows what it is made of. We find then that white sunlight is composed of light of the colours just mentioned, and the same instrument can also be made to show us that any colour which is not seen to exist in the band of colour directly, can be obtained by mixing some of the colours which are already there.

If we had a light in which any colour was absent, objects which possessed that colour in daylight, when viewed in that particular light would appear black. The explanation of this is of course to be found in the fact, which we repeat, that the object is coloured because it reflects light of its colour. If that light is not there to be reflected the object necessarily looks black.

The commonest example of objects which emit coloured light of themselves, and so appear coloured, is that of fireworks, but instances of this sort are so rare comparatively that there is no need to do more than mention them.

The colours in the spectrum, as the band of coloured light as it emerges from the spectroscope is called, are said to be *pure colours*, because, however often we take any of them and send them through further spectroscopes, we do not get any different colour than the one we started with. Objects in nature, however, although they may have a very well-defined tint, such as blue red or yellow, when critically examined will be found usually to reflect light more or less of all colours, so that their actual tint is a kind of hotch-potch, in which blue yellow or red as the case may be, simply exercises a predominance.

When photography was discovered everyone seemed to think that photographs in natural colours would soon be obtained. Photography itself was so wonderful that it seemed but a very little step further to get the pictures in colours. Consequently, the early history of photography is crowded with cases of inventors who sought for this result, and in many cases thought they had attained it. Curiously enough, some of these early workers did undoubtedly secure photographs in colour by having unconsciously employed a process to which reference will be made later on, called the Lippmann process. As they did not know how it was that they got them, they could not often repeat the experiments. They thought that the colours were due to trivial chemical differences in the manipulations, while they were actually caused by the physical conditions under which the exposure was made.

To most people a photograph in natural colours means a photograph which, when looked at as a painting is looked at, shall, like a painting, appear with the various objects sending to the eye coloured rays of the same tint as they had in reality. Now to secure such a result by a single straightforward process, in which the photographic practice of making a negative and subsequently a print is to be followed, we require to have a sensitive salt capable of giving on exposure to coloured light a product which shall possess the colour of the light which falls upon it, or which fell upon the plate on which the negative was made.

Needless to remark, no such substance is known. Though it is possible that chemists may subsequently find such a substance, it is not at all probable. Were we but to know of a substance which under any treatment whatever would yield all the colours, we might think there was some chance of finding one in which the action of light would bring about such a result. But it is only a small minority of the substances that we know which are appreciably affected by light at all, while we do not know of any substance whatever which under any circumstances can be made to yield all colours. Hence the problem of photography in natural colours, using the words in their simple and straightforward meaning, seems insoluble, and it only remains to describe the ways in which the Gordian knot has been cut.

2.—*The Undulatory Theory of Light.*

In the last chapter we considered the cause why different objects present to our eyes what we call colours. In most cases it was said to be due to the fact that white light, consisting of a mixture of all colours, falls on them, and that they exercise a selective power, absorbing some of the light and reflecting the rest. The colour of the reflected beam we call the colour of the object. We now have to see what is the nature of light itself, and what constitute the differences between light of different colours.

Amongst scientific men it is now universally agreed that the most satisfactory explanation of the nature and behaviour of light is that which is known as "the undulatory theory." Any attempt to set out here the reasons for this entire consensus of opinion would be quite out of place; it must suffice if we give just those portions of the theory which are necessary in order to understand what follows.

Light, according to this theory, is not matter but is motion. The ripples on a pond are taken as the usual example of motion. They are not matter, although the water on which they are formed is matter. If they were matter their substance would travel with them, but when a stone is thrown into a pool, and the ripples travel outwards to its edge, it is the ripple and not the water that travels. At first sight it is hard to realise that the water does not move outwards with the ripple, but it does not.

This can easily be seen if a few very light pieces of paper are thrown on to the surface of the pond. If they were thrown into a swiftly-flowing river they would travel practically as swiftly as the water, so long as they floated freely on its surface. But in the pond the ripples pass the papers by. They move up and down with each ripple, but they do not come to the edge with them. A better illustration might be the wave easily sent along a rope, that is not too tightly stretched, by shaking one end. If the rope is long enough the wave can be seen travelling along it, and reflected back from the other end, although, the rope being fastened at each end, each part of it remains as far from the ends as ever, merely moving in a direction at right angles to that of the rope itself and of the wave.

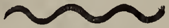
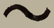
It is impossible to conceive of motion existing without some material substance being moved. We know that light passes freely through glass, water, transparent stones, air, and the spaces between the earth and the heavenly bodies where none of these substances can be believed to exist. Something then, which, in motion, constitutes light, must pervade all these things; it must extend from us to the furthest star from which any light reaches us; it must be capable of moving even when enclosed among the particles of a mass of glass or a tank of clear water. Such a substance is supposed to exist, and has been christened "the ether." There are other reasons for the belief that there is such a form of matter, although the wave theory of light would be sufficient to compel its acceptance.

In this ether, light is supposed to be a wave-like motion or disturbance, which travels with an enormous but perfectly measurable speed, and in a straight line. The actual rate of travel does not concern us, but the direction of the motion does.

Let us imagine that the particles of ether, in motion, are each separately visible, and that right in front of us from right to left is a beam of light, that is to say a row of the ether particles in motion. In which direction does each particle move? We know that in the case of ripples on the pond, the ripples travelled from the centre to the edge of the pond, while any particular drop of water—that, for instance, on which our piece of paper floated—merely went up and down. Will this be the case with the ether?

Physicists answer yes! If we looked, broadside on, at our beam of light we should see the ether particles moving, not in the direction in which the beam was travelling, but up and down, or towards us and away from us, or at any rate in some direction quite at right angles to the path of the light itself. If they were moving up and down, and we looked across such a beam, we should see the row of ether particles which, when there was no light, and therefore no disturbance, were in one straight line were now in a wavy line—in a line, in fact, forming like the ripples on the pond a perfectly even succession of waves.

If instead of looking at the beam of light broadside we regarded it end on, and only noted one of the ether particles, we should see it go up and down, up and down, along the same path time after time. It would get no nearer to us, although the wave itself would.

Returning to the position in which we could see the beam of light broadside on, the wave would present somewhat this appearance  Each one of the curves  is considered as a complete wave, and the distance in a straight line from end to end of it is called a wave-length.

The difference between light of one colour and light of another colour is found in the *size of the waves*. Not in their height but in their wave-length. Everyone has seen the solar spectrum or some representation of it. A band of colour red at one end passing by imperceptible degrees from red through orange, yellow, green, and blue to violet. In the solar spectrum the position of the colours is proportional to their wave-lengths when the apparatus used is of a suitable character. Thus the red light has the longest wave-length, and the violet the shortest, and the rest come in between.

These waves are so small that it is easiest to invent a new unit with which to measure them. Let our unit be the one-millionth part of an inch. Then in red light we should find waves about thirty times as long as our unit, and in the violet only about fifteen times as long.

There is no other difference, so far as can be detected, between light of different colours than this one of wave-length and differences resulting from it, and we shall see in the next chapter how this theory of waves has been taken by Professor Lippmann, and a process of photography in colours worked out upon it.

3.—*The Lippmann Process.*

If the reader has studied what has preceded the present chapter, he will have some idea of the way in which light and colour are regarded by scientists at the present time. Light, he will know, is looked upon as a motion or disturbance in the ether, partaking of the nature of a wave. Let us see what happens if we have two waves meeting one another, under various conditions.

It will be best to return for the time being to the simile of ripples on the surface of a pond. Let us think what would happen were a series of ripples going from the centre to the edge of the pond to meet another series of exactly the same size travelling from the edge to the centre. If the crests of one set of waves came in exactly the same place as the crests of the other set, it is only reasonable to suppose that their joint efforts would exceed what either could do alone, and that we should have a series of waves of greater height than we had when only one disturbance existed. If, on the other hand, the waves were of the same size, and it so happened that the crests of one series fitted exactly over the depressions of the other series, it is quite possible to suppose that they would exactly neutralise one another, and the surface of the water would remain absolutely calm, without a single ripple.

It is not easy to arrange such a state of things in the case of a pond, but it is quite easy, and, indeed, a stock experiment in physical laboratories, so to arrange the beams of light that the crests of one set of waves exactly fit into the hollows of the other, the two disturbances neutralising one another, and the result of adding the two beams together being not more light, but darkness.

In white light we saw that we have a mixture of all the colours, that is, we have all sizes of waves between the extreme limits which constitute light. Hence it is easy to see that we could not expect perfectly to fit all these waves with a corresponding series, so that they are all exactly neutralised. This experiment can only be performed when light of one size of wave is employed. It is possible, though, to reflect a beam of white light back upon itself in such a way that some of the reflected light shall neutralise some of the direct light that it encounters.

A little thought will show that when this is so some sizes of waves will be neutralised, and other sizes unaffected. In other words, there will be a selective action. We saw in the last chapter that whenever there was such a selective action exercised as regards white light, the result was colour. A red ribbon in sunlight looks red, because it picks out the red light and reflects it to the eye and absorbs the rest. If we have two reflecting surfaces close together, both sending a portion of the same beam of light to the eye, if the distance apart of the two surfaces is very small, it is quite possible that one set of waves may have travelled just half the length of one of the waves farther than the other.

If two waves are drawn upon a piece of

paper, side by side, but one just half a wave length behind the other, it will then be seen at a glance that the crests of one will come in the same place as the depressions of the other, and the result in the case of light would be that one would neutralise the other. In order to get this result, the distance of the two surfaces apart must, therefore, be such that one wave is just half a wave length before or behind the other. The light of that particular wave length will then be neutralised, and the result will be that the light, white originally, when reflected from two such surfaces, will be the colour which white light would present were the particular colour which has been neutralised subtracted from it.

It is clear that the surfaces must be very near together, and not many things can be made so thin. The simplest case is the thin film of soap-suds in a soap bubble. The walls of the bubble are so thin that the light reflected from the inner surface of the bubble and that reflected from the outer surface interfere with and neutralise one another. The particular colour so neutralised depends upon the thickness of the wall of the bubble, and, as this is changing constantly, so the colours change. The colour of a bubble then is that of white light, *minus* the rays of that particular size which have "interfered with," or neutralised, one another. The brilliant colours seen when a few drops of tar or turpentine float on a surface of water are caused in the same way—they are said to be due to "interference."

Wherever light is reflected back upon itself, as from the surface of a mirror, this interference also takes place, but not to such an extent as to be visible to our eyes, because for one reason, the light is falling on the mirror in all directions. Being reflected in all directions, the eye can recognise no predominating division of the rays into two beams (one of which is reflected from the front surface and the other has travelled just twice the thickness of the film by passing through it and being reflected from the back surface) that it can when looking at a soap bubble. None the less, this interference is taking place, and at a very minute distance from the surface of a mirror it can be shown to exist.

Let us imagine a brilliant reflecting surface coated with some sensitive transparent coating and exposed in a camera. The light coming through the lens passes through the sensitive film and falls on the reflecting surface from which it is sent back upon itself. Where the reflected ray and the original ray reinforce one another—where the crests of both their waves coincide—there will be a lot of light action on the sensitive substance; where they oppose one another there will be none.

This, or something like it—for the operation is really very much more complex—takes place in what is called the Lippmann process. Glass is coated with emulsion of a perfectly transparent nature, and exposed in the camera with the glass side to the lens, and with the film side backed up with mercury. In this way we have a brilliant mirror of mercury in close contact with the film, and reflecting back upon itself the light that comes from the lens. The film must be transparent or it scatters the light, and it must be thick enough for one or two complete light waves of the biggest kind to be fully formed within it. Where the light action as mentioned in the last paragraph is strongest, there will be a layer of image when the plate is developed, and where it is weakest there will be a blank layer. The existence of these layers has been proved by Dr. Neuhauss, who cut such a film into sections, and photomicrographed it in such a way as to show the layers distinctly. A remarkable feat.

The result of this is that when a plate has been exposed, developed, and dried, we have a film upon the glass in which the image consists of a series of extremely thin layers of deposit (silver) separated by equally thin layers of no deposit, merely the clear vehicle (gelatine) employed. When these layers are looked at in light which falls upon them at a suitable angle, they show colours just as a soap bubble does, because the light reflected from one layer interferes with that reflected from the next.

Further, we have this fact which a little thought will render plain. The distance apart of the layers depends upon the size of the waves, in other words, upon the colour of the light. Hence in the image formed by the lens, the parts which were red in the original object, being formed by red rays, will have their layers further apart than those of the violet parts formed by smaller waves.

The remarkable fact about this is that when these pictures are looked at in light falling at the proper angle, the interference is such that the parts which were red in the original look red in the picture, and so on, the colours being to some extent true to nature.

This is the Lippmann process in outline. No directions are given for working it, because they are easily accessible, and would run to a great length. It seems very simple, but very few persons have succeeded with it; we doubt whether, all told, a dozen have worked it with any degree of success.

When the spectrum is used, the colours are often remarkably true. When coloured objects, landscapes, etc., are photographed, they often are but mere suggestions of the tints of the original, sometimes glaringly wrong. They have to be examined under special conditions of lighting to see the colours at all. To secure a perfectly transparent film—an absolute necessity—the sensitive emulsion is extremely slow.

From this it will be seen that the process, while one of great scientific interest, and of a most beautiful and curious nature, is not in any sense a practical one, and does not give results which are what commonsense people, using the words in their natural undistorted meaning, would describe as photographs in natural colours. All the same, it is the only process yielding all the colours in one simple straightforward manner. It is also one which stands quite by itself in theory and in practice, and on these grounds deserves consideration before all the others, in which the results may be more generally acceptable, but in which the means adopted are of a roundabout and indirect character.

4.—*The Principles of Colour Vision.*

Hitherto we have discussed only the fundamental difference between light of different colours. Before we can profitably consider the various processes which come under the head of "Three-colour" work in photography, we must pay some attention to the way in which different colours affect the eye, and through the eye the brain.

The total number of colours and shades must be something enormous. If we run down a list of paints, such as that issued by Rowney, we find dozens and dozens named, and a sample patch of each given; between each of these the eye can clearly note distinct differences. How does it do this? is the question, and the answer which modern science gives it is now our task briefly to summarise.

The theory of colour vision which is now generally accepted bears the name of "Young-Helmholtz," because it was first promulgated by Young, and more elaborately worked out subsequently by the great German physicist, Helmholtz. It supposes that in our eyes three distinct forms of stimulus can be received. Whether there are three distinct sets of nerves, one responding to each, or whether one set of nerves can be excited in three different ways, is not known. What is known is that we experience the sensation of colour when one, two, or three of these stimuli is experienced at once, and that according to the degree in which one or other of these three actions takes place, so is the "colour" seen. If we could sort over all the different colours that light can assume, we should find one which gave rise only to one of these sensations, another which gave rise to another only, and a third in like manner. This can be done, and is done every day.

One of these sensations is called the "red sensation." We experience it when we look at a deep, pure red. Another is called the "green sensation," and a third the "violet," or the "blue-violet sensation." If we find out exactly what colour of light corresponds to each of these, we can mix these three lights in varying proportion, and so can give rise to a compound sensation corresponding to any colour whatever. There is no colour in all the long list referred to which could not be imitated exactly with these three tints by mixing them suitably. We might want only one of our three, we should more likely want two, or even all three, but with the three we could exactly copy any colour whatever, as far as the eye is concerned.

What we have said above as to the mixing of lights must not be confounded with the mixing of paints. This is very different, as we shall see at a later stage. At present we are considering merely the mixing of coloured lights, such as might be got by three lanterns, each throwing a coloured beam on the same patch of white paper. If we put a suitable red glass in one, green glass in another, and violet glass in a third, and had all three lanterns at the right degree of brightness, a piece of white paper, upon which all three were shining, would look white.

Such a piece of white paper in the red light alone would look red. In the violet alone it would look violet, and in the green green. If the green and red shone upon it together, it would look yellow. If the green and violet did so, it would appear blue. If the red and violet did so, then the paper would appear crimson.

The eye then perceives all colours by the degree to which each of these three sensations is set up. Any particular object—take a green leaf, for example—is giving rise to a very powerful green sensation, and, as pure colours are not very common in nature, it is probably exciting to some extent, but to a much less one, the red and the violet sensations. The red fruit, on the other hand, is exciting the red sensation to a great extent, the green hardly any, the violet, perhaps, a little more so if the red inclines to crimson. The wings of a white butterfly on the tree excite all three sensations to give us white, or, if the butterfly's wings are bright yellow, they are exciting the green and the red sensations. And so on, all through nature and art. The combinations of these three sensations give us every colour.

Some people have not this three-fold sensitiveness in the eye. Many are met with who are quite incapable of receiving the red sensation. Sometimes, but much more rarely, the green sensation cannot be excited. People in whom one of the colour sensations is wanting are said to be "colour blind." It is a great drawback to them, but thanks to their shortcomings the theory of colour vision has been aided to no small extent.

Such a theory, supported as it is by a mass of evidence, quite out of place here, clearly suggests that it might be possible, by taking three photographs of the same subject, to obtain three plates, one of which records the way in which the object excites the red sensation, one the green, and one in the same way the blue-violet. The photographs might not be coloured themselves, but they might act as records of the colour. This is, indeed, the basis of all three-colour processes, which depend first on securing three distinct records, and then on viewing these records simultaneously in such a way that they give rise to the same colour impression as did the object.

We might add here what we omitted, for the sake of clearness, to say above, and that is that no one colour excites one colour sensation, and one only. There is a certain amount of overlapping, but it may be disregarded by us in the present case as not affecting the main principle.

5.—*The Ives Processes.*

In the last chapter we pointed out how it came about that given three suitably selected colours every conceivable tint could be obtained by their admixture in various proportions. This is the basis of all "three colour" work. No name in connection with this subject is so well known as that of Mr. Frederic Eugene Ives, of Philadelphia, to whom is due the working out of the beautiful methods and apparatus we shall describe in this chapter.

In all these processes the first requisite must be the three negatives. An examination of the matter of colour vision, as given in the last chapter, shows that if we look, for the sake of simplicity at the spectrum let us say, the nerves or mechanism in the eye excited by the red are also, but to a less extent, excited by the yellow, and to a still less extent by the green. In the same way the mechanism most sensitive to the green is sensitive to some extent to the red on the one side and to the blue on the other, and a similar thing holds good with regard to the blue-violet. In other words, the sensitiveness of these three "nerve fibrils" or apparatus on the retina of the eye is not abruptly limited to the one particular colour which most strongly stimulates them, but is, as it were, "vignetted off" on both sides.

Clerk Maxwell, and still more recently Sir W. Abney, have expressed the sensitiveness of each in the form of curves, such as are often employed nowadays to show how effects increase or decrease with modifications in their causes. The height of the curve above its base line increases as the particular colour sensitiveness is excited, the base line being marked off to represent the spectrum. We thus get in the case of the red sensitiveness a curve which starts on the base itself at the extreme red end of the spectrum, rapidly rises until we get to the border of the red and orange, where it is at its highest, and then tapers off, not reaching the base again until the blue-green. The other curves are similar.

Now it was one of the points upon which Mr. Ives laid the greatest stress that each of the three negatives should correspond strictly with these curves. That is to say, that if instead of a coloured object the spectrum itself were photographed, the density in the negative intended to record the way the red sensation was excited must increase as we travel along the spectrum in the same way that we saw the curve ascend. The greatest density must be in that part of the spectrum which excites the red sensation most strongly, and the deposit must tail off and finally disappear in the blue-green at the point where the curve met its base line again. The other two negatives must correspond in the same way with the curves which represent the green and the blue-violet sensations.

In order to get three such negatives, plates must clearly be used which are themselves sensitive to all the colours. Some people still like to do as was done in the early days of three-colour work, and to employ one kind of plate for one negative, and another for another. It very much simplifies matters though, and this is the course Mr. Ives himself now advocates, if the same kind of plate and even the same plate itself is used for all three, the three being on different parts of it. For this purpose such plates as Cadett Spectrum or Lumière's Panchromatic can be employed.

Suitable screens or colour filters have to be interposed so that only those rays are allowed to act upon the plate as go to excite the particular colour sensation in the eye. Such screens are now matters of commence. They are usually made of dyed gelatine or collodion hermetically sealed between two pieces of perfectly flat glass. They are placed either before or behind the lens or between the lenses during exposure. In some cases they are put immediately in front of the plate, to the colour sensitiveness of which they have to be suited.

In practice usually a "repeating back" is used. This allows one-third of the plate to be exposed in the camera, while the red screen is in position, the next while the green screen is used, the remaining third with the blue-violet screen. Of course, separate plates in separate dark slides can be used with each if they are preferred. The exposures being carefully proportioned, it only remains to develop the plate or plates together, and to finish the negatives off in the usual way.

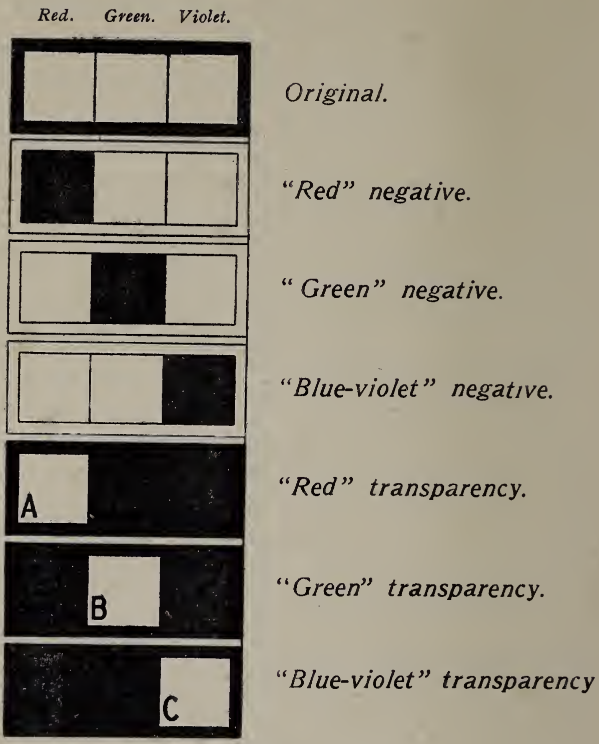
Mr. Ives has constructed a camera which on the principle of the photochromoscope itself (to be subsequently described) takes all three pictures with one lens at once. It is a marvel of ingenuity, but the care and skill which its adjustment require put it out of the question as an everyday instrument.

The three negatives so made, it remains to use them. Transparencies are made from them by any of the ordinary lantern slide-making processes. Of course, these slides do not show the slightest colour, but they *record* the colours of the original notwithstanding, and can be made to repeat it.

Let us see how they record it, for a moment. We will take as a subject a piece, say, of paper coloured in three squares, red, green, violet. We will ignore, for the sake of simplicity, the "vignetting" of the colour sensations into one another, just referred to; the result is the same. Our "red" negative of the paper shows deposit on the red square, none on the green, and none on the violet. The "green" negative shows no deposit on the red, some on the green, none on the violet. The "violet" negative shows none on the red and green, but some on the violet. The transparencies are the reverse of these, and are opaque all over *except* on the red patch in the case of the "red" transparency, on the green in the case of the "green," etc. These are shown in the diagram on the next page.

Now if we had three pieces of glass, one red, one green, and the third violet, and put the first behind the "red" transparency in the figure, the second behind the green, and the third behind the blue, if we could manage to see all three transparencies in the same

DIAGRAM OF THE THREE-COLOUR PROCESS.



This is intended to show—in a diagrammatic manner only—how by the use of suitable plates and colour screens three negatives may be made from an original, recording respectively the red, the green, and the blue-violet in the subject. From these transparencies or positives can be made by any of the well-known photographic processes, which when each is illuminated by light of the colour it records, and all are seen simultaneously and superposed, the colours of the original are reproduced.

place at the same time, we should clearly have a reproduction of our original. This, because the transparent part A would allow us to see the light coming through the red glass, B that through the green glass, and C the violet.

An instrument for seeing all three pictures at once is what we have in the Ives "Photochromoscope." Its principle is shown in the figure, which is a diagram representing a section through it. The eye is placed at E. The "red" transparency and its red glass are placed at R, the green at G, and the blue-violet at B. The lens at E gives a magnified image. C C are reflectors of coloured glass, which reflect the transparencies at R and B respectively, but which allow that at G to be seen through them. A reflector is placed at D, and the instrument is supported at a suitable angle for convenient observation by the baseboard F and the strut H. The light is shown by the lines L L.

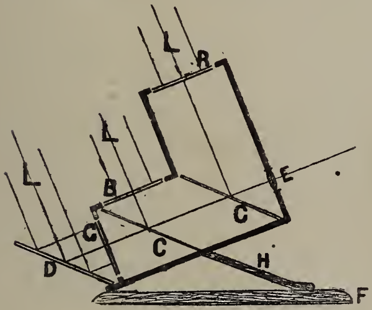


FIG. 2.

The photochromoscope as usually made does more than this, inasmuch as each transparency is a stereoscopic pair, and there are two lenses at E, one for each eye. In this way we not only see the colours of nature, but obtain the stereoscopic effect as well.

It is impossible to realise when looking into this apparatus that what is seen is simply the combination of three colourless transparencies—the illusion is so perfect.

In addition to this piece of apparatus, Mr. Ives has devised a triple lantern, for projecting coloured images on a screen. This has three lenses, and the three transparencies, each illuminated by light of its own colour, are thrown one on the top of another on a white screen. Here, again, the brilliancy of the colour and the delicacy of the shades which the instrument can reproduce with perfect truth are remarkable.

6.—*The Joly Process.*

When a painter wishes to obtain a tint of a particular character he may sometimes resort to the plan not of mixing his paints together on the palette and then applying the mixture to the paper, but to a kind of fine stippling in which the colours are not placed one on the top of another, but are put side by side in minute dots.

If pictures reproduced from photographs by what is termed the half-tone process are examined, it will be found that the shades of grey which constitute the half-tones in such illustrations are not obtained by covering the paper with a grey ink, but simply by a fine stipple of black dots upon white paper. All the dots in a very pale grey tint are quite as black as they are in the blackest shadow, the difference not being in the colour of the ink, but in the size of the dots. When such illustrations are looked at from a distance of a foot or more the dots are so small that the eye does not perceive them *as dots*, but simply obtains the general effect of the white paper and the black dots: such effect being a grey, the exact tone of which depends simply upon the size of the dots themselves—or, in other words, on the proportion between the surface of the paper covered by black ink and that left white.

If paper is shaded with fine lines or dots of different colours, and is then looked at from such a distance that the eye cannot distinguish each separate line, the paper appears to be of a smooth and even tint, the exact colour of which is a compound of the whole.

This blending of fine lines or dots in the eye is the basis of a very clever modification of the three-colour process, due to Professor Joly of Dublin.

Instead of making three separate negatives of any coloured object through three distinct colour screens, as described in the last chapter, let us suppose that one negative only be taken, and that, instead of employing a colour screen of uniform tint, there be placed immediately in front of the plate, and in close contact with it, a screen which is composed entirely of very fine lines, close together and of equal width, of red, green, and blue-violet colour respectively. The lines are in the same order right across the screen, thus—red, green, blue-violet, red, green, blue-violet, red, and so on. What would happen when an exposure is made?

We will take the case of a red object. It reflects red light only (or we will assume that it does for the purposes of explanation). This red light has to pass through the coloured lines of the screen before it can reach the plate; the blue-violet lines stop all light passing through except blue-violet, and as our object is only reflecting red light, no light therefore reaches that part of the plate which is immediately behind the blue-violet lines in the screen. The green lines in the same way stop all light but green, and as we have only red light in the present instance, no light reaches those parts of the plate which are immediately behind the green lines in the screen. On the other hand the red lines which allow red light to pass unaltered, but absorb all other rays, allow the whole of the light (since it is entirely red) to pass through them, and affect the plate in those parts.

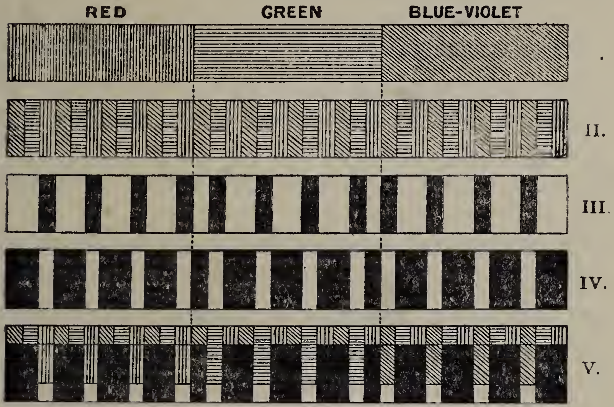
When we come to develop such a plate we should find the image composed entirely of deposit in black lines where the red lines of the screen came against the plate. Where the blue-violet and green lines came against the plate there would be no deposit at all. Hence, as the lines on the screen are of equal breadth throughout, we should find across our plate a series of lines separated by a series of transparent spaces, the transparent spaces being twice the width of the black lines. This state of things will be seen on reference to the figure given on page 41, which is intended to show diagrammatically the various stages in the production of a "Joly" transparency.

Taking such a negative as we have described, and making from it a positive transparency by contact, clearly we shall have a positive composed of black lines twice the width of the transparent spaces which separate them.

Let us suppose we place such a positive in contact with the colour screen through which the original negative was made, so that those parts of the transparency which correspond to the parts of the plate that lay originally immediately behind the red lines of the screen come once more immediately behind those red lines, and the other portions behind the other lines in the same way. On looking through the positive and screen together, we shall see a series of red lines only, because the portions corresponding to the blue-violet and to the green lines are opaque in the positive transparency. In fact, if all had been conducted properly, we should see nothing but the red lines of the screen. If we got sufficiently far away from such a screen, or if the lines were sufficiently fine for the eye not to be able to distinguish them as lines, we should simply see an uniform red tint. In the same way if our object had reflected blue-violet rays only, we should see a blue-violet tint, or if green rays only a green tint.

To secure this result it is clearly necessary in the first place to have a screen ruled in suitable colours with very fine lines, and, in the second, to take care that the positive transparency is placed for viewing purposes upon the screen in such a position that the lines upon it strictly correspond with those which were upon the screen during exposure. If the lines on the negative which were behind the red lines on the screen when viewed are placed behind the green lines on the screen, the red parts of the object appear green, and the other parts are correspondingly changed.

This is, in outline, the Joly process of colour photography. Were we always dealing with pure colours as we have assumed, the process would be of the extremely simple nature that we have given, but in actual practice all sorts of compound shades are met with. These are, however, reproduced faithfully in the photograph by varying degrees of opacity in the different lines of the positive, which allow varying quantities of the different colours to be seen and blended by the eye. From what we have said it will be seen that this process is essentially a three-colour process, in which all three negatives are obtained on one plate in a series of fine lines, lying side by side. Many of the difficulties of three-colour work are thus done away with, and the process is one which, although by no means as easy as ordinary photography, is still within the capabilities of any careful photographer.



The stages of making a colour photograph by the Joly process shown diagrammatically. I., the original; II., the ruled screen; III., a negative taken through the screen; IV., a transparency from the negative; V., the screen partly viewed through the transparency. Note how in this the colour of the original, indicated by the shading, is reproduced.

In actual practice there are a few differences from the bare outline we have given. For instance, the transparencies are not viewed through the same screen as that employed to take them. The photographic plate does not record colours as the eye sees them, as all photographers know, and therefore a compromise has to be effected. This is done by having two distinct kinds of screens, one called a "taking screen," modified to suit the peculiarities of the photographic plate, and the other a "viewing screen," so arranged that when the transparency is looked at through it the colours of the original object shall be reproduced as the eye sees them, and not as the orthochromatic plate, however carefully corrected, must render them.

Clearly the screens themselves when looked at so that the individual lines are not seen should appear free from colour, that is to say *white*. As each of the coloured dyes with which they are ruled cuts off some of the light, the screen can never appear white, but of a greyish tint. The dyes, however, are adjusted so that this tint shall be practically free from colour, although made up entirely of lines of brilliant green, red, and blue-violet dye. The Joly process, giving as it does transparencies, is particularly suited to the making of lantern slides. Many of the results obtained with it can be purchased, and make very striking examples of its power. If they are magnified greatly on the screen the lines can be easily seen by an observer who is near to it; at a little distance they blend, and then the colours are wonderfully faithful.

7.—*Coloured Lights and Pigment Colours*

It is essential before we can go another step further in our account of three-colour work that the reader shall have a clear idea of the difference between the results obtained by mixing coloured lights and those by mixing colours or paints such as the artist employs. We have heard painters ridicule the theories of colour and colour vision because they show that the mixture of, say, red and green gives yellow, whereas "any fool knows" that it is not so. We have ourselves been challenged to mix pigments to produce the results which theory shows must follow from mixing coloured lights. We have therefore endeavoured, at the risk of being accused of repetition, to make the distinction as clear as possible, and to point out that theory and the painter's practice are in entire harmony.

Those who have followed with care what has preceded this will remember that we pointed out that with light of three colours, red, green, and blue-violet, any colour in nature could be matched. We mentioned that red and green produced yellow, green and blue-violet—blue, blue-violet and red crimson; in spite of the fact that red and green paint mixed do not give us yellow, but that yellow and blue paint do. This is typical of the difference between the mixing of lights and the mixing of pigments.

Let us consider what happens when a painter colours a piece of paper previously white. The paper appears white to us because it reflects back unaltered the white light falling upon it. Wash it over with gamboge, and it appears yellow. Why? Some of the light falling upon it is still reflected back, but it has twice passed through a thin layer of gamboge, once on its way to the surface and once after reflection on its way back. The gamboge has absorbed some of the blue and violet rays in the light, and the blue-violet sensation is no longer excited in the eye by the light from the paper, but only the red and the green sensations. The combined effect of these two sensations is the compound one we call yellow.

So far the behaviour of the paint and of the coloured light are similar. If we hold a piece of yellow glass in the path of a beam of white light the light looks yellow because the yellow glass, like the gamboge, absorbs blue-violet rays.

Let us now wash over our yellow paper some transparent blue pigment. The paper at once has a green appearance. If we like we can reverse the order of things, and coat the paper with the blue first, and then wash it over with yellow. The result is the same—a green tint.

We will first note what effect the blue pigment has, by itself, upon the paper. It absorbs the red rays in the white light passing through it, but allows the green and the blue-violet rays to pass. These reaching the eye excite the green sensation and the blue-violet sensation, and the compound sensation of these two we style blue.

When the paper has been coated with both the blue and the yellow paint, either in separate layers or mixed together (we need not notice the differences here), the white light falling on it has to pass through two layers—a compound layer—the gamboge absorbs the blue-violet rays, leaving the red and the green unaltered. The blue absorbs the red, leaving the green and blue-violet unaltered. The result of their joint efforts is the absorption both of the blue-violet and the red, and the only rays left to reach the eye are those which give rise to the green sensation. Hence we say the paper is green.

If we mix light of different colours and not paints, the result is quite different, as a moment's consideration will make clear. Let us suppose we have a white lantern screen and two lanterns, one containing a yellow glass, so that the screen when lit by it looks yellow, and the other a blue glass, so that the screen when lit by it looks blue. When lit by both lanterns the screen will not appear *green* as when the paints were mixed, but *white*.

This is clear enough if we follow it out. The yellow light excites the red and the green sensations. We add to that the blue light exciting the green and the blue-violet sensations, and, as a result, we get all three sensations, the red, the green, and the blue-violet excited, to which we give the name of white.

If instead of putting a yellow glass in one lantern and a blue in another, we put both in the same lantern and send the beam of white light through both, then we should have a state of things similar to that in the case of the paints just mentioned, and the screen would no longer appear white, but green. It can only appear white if all three sensations are proportionally excited; and if the beam has to pass, as it does when there is only one lantern, through both yellow glass (absorbing blue-violet) and blue glass (absorbing red), green light only can reach the screen.

The importance of getting a clear idea on this subject is so great, if colour photography is to be understood at all, that we propose to go over this once more in the form of two sums. One, the case of paints, is a subtraction sum, and the other an addition sum. In each case we start with white light, which we regard as a mixture of red, green, and blue-violet.

White light	= Red, green, blue-violet
Gamboge absorbs	blue-violet
Leaving	Red, green
Blue paint absorbs	Red
Leaving	Green

Paper coloured with yellow and blue paint therefore looks green.

In the case of throwing coloured light upon a white screen, we start with our screen in perfect darkness. It is only white in white light, and in darkness therefore we regard it as reflecting nothing.

Screen in darkness reflects ...	—	—	—
The lantern with yellow glass throws upon it	—	Green,	Red (= Yellow)
It therefore appears	—	Green +	Red (= Yellow)
The lantern with blue glass throws	Blue-violet,	Green	— (= Blue)
The screen therefore appears	Blue-violet +	Green +	Red (= White)

Were the proportions of green to red in the yellow, and of blue-violet to green in the blue, in each case the same as they are in white light, we should get a screen of a greenish white, because we should have a double quantity of the green in the last line. Still, the colour of the screen would be essentially *white* and not green.

We have taken the case of blue and yellow simply because it is that which is most likely to arise first in a reader's mind. He is so accustomed to mixing blue and yellow paint to get a green that the statements that blue and yellow light do not have the same effect, that yellow is the result of mixing green and red light, and so on, are apt to be startling. Of course, any other of the painter's mixtures might be taken with an equally-wide difference, and this must always be kept in mind when there is any risk of confusing the mixture of pigments and the mixture of lights.

The strongest example of all is that the mixture of red, green, and blue-violet light gives us white, the mixture of red, green, and blue-violet pigment gives us—what? Let us see. The red paint absorbs green and blue-violet, only allowing red light to pass through it. The green absorbs blue-violet and red only, allowing green to pass through it. The blue-violet in the same way only allows blue-violet rays to pass. The three mixed together therefore give us black. More than that, any two of them are together sufficient to give us black.

To put it in the form of an allegory. There are three robbers, of whom Red allows his victims to keep their coppers, if they give up their gold and silver; Green makes them hand over their gold and coppers but lets them retain their silver, while Blue-violet, with a degree of self-denial not met with in the case of the others, lays hands merely upon their silver and pence, and allows them to retain their gold. Any unfortunate traveller such as White Light, Esq., falling into the hands of two of these three ruffians, loses all his cash. It matters not, as far as he is concerned, which two it may be, the result is the same.

The vital importance of all this in three-colour work will appear in the subsequent chapters.

8.—*Three-colour Lantern Slides.*

We now come to a form of the three-colour process which has been attracting a great deal of attention of late. We have seen in the previous chapters how three negatives can be made representing the three "colour sensations" aroused in the eye by the subject; and we saw also how transparencies from those negatives could be employed in the photochromoscope and in the Ives lantern. In this connection, after that of Mr. Ives, whose work underlies that of all the later investigators, no name is more prominent than that of Mr. Sanger Shepherd, and it is to that gentleman that is largely due the practical working out of the method of making lantern slides in colour which we here describe in outline.

Those who studied the last chapter carefully will, we hope, be able to follow this without any difficulty. Those who did not, and are not acquainted with the essential differences between pigments and coloured light, must either turn back to it or be content to pass by the process which is now to engage our attention.

It is plain that if we are to have a lantern slide capable of being placed in a single lantern, and showing the colours as yielded by the three-colour process, we cannot employ in our slide the colours used in the process already dealt with.

Lest this should not be sufficiently clear, let us take an example, a green object for instance. Our negatives taken through the red and the blue-violet screens respectively, represent it as a transparent patch; that taken through the green screen as an opaque patch. If we printed each negative on a piece of carbon tissue, having as its pigment a colour similar to that of the screen employed, we should have a patch of blue-violet tissue and of red tissue superposed on a clear space on the green tissue. As blue-violet + red cut off between them all the light falling upon them, our green object would appear black. Some other course, manifestly, must be adopted. What that course must be we will proceed to explain.

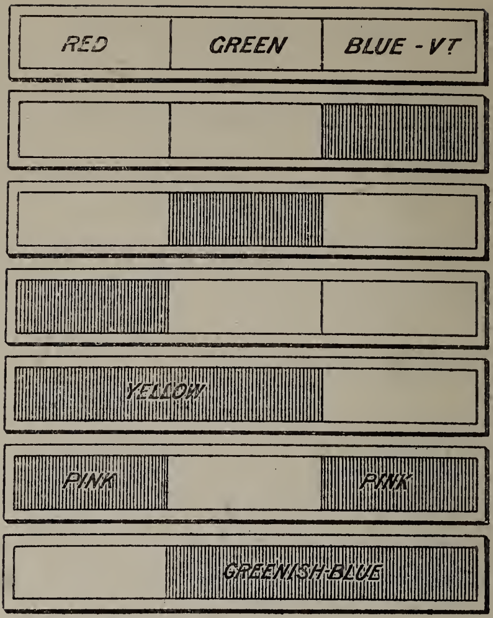
We have seen that the sensation we call white can be aroused by a mixture of blue-violet, green, and red lights. If the blue-violet is missing we get a yellow. Yellow may then be regarded as white minus blue-violet. If the green is missing we get a pink or crimson; pink then is white minus green. In the same way greenish-blue is white minus red. These terms are those employed by Mr. Sanger Shepherd, and help to make the matter clear.

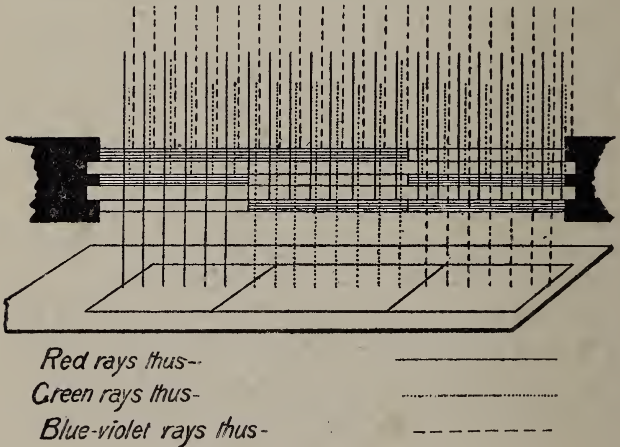
Suppose we print from our negatives of the green object we took as an example, in tissue of the three colours just alluded to—yellow, pink, and greenish blue. The print from the blue-violet negative gives us a patch of yellow, as that is the colour we print it in. The red negative gives us a greenish-blue patch. The green negative being printed in pink, and being the only one on which there is a deposit, gives us a blank white space. To ascertain the colour which these three slides will show when placed in a lantern we must perform another sum in subtraction:

The light from the lantern is ...	Blue-violet, Green, Red (=White).
The yellow slide allows only green and red to pass, that is it cuts off the ...	Blue-violet — —
	— Green, Red (=Yellow).
The pink slide has no deposit, being printed under an opaque patch on the green negative	— — —
	— Green, Red (=Yellow)
The greenish-blue slide allows only green and blue to pass, *i.e.*, cuts off the	— — Red
The only colour that will reach the screen is therefore	— Green —

As this was the original colour of the object, it is seen that we have attained the desired result. It can be shown in the same way that any of the three simple colours we are considering can be repeated by this process, and compound colours are obtained in the same way, the transparencies allowing a little of one and perhaps more of another colour to pass, according to the densities of the three-colour negatives from which they were made.

Perhaps the figure (p. 52) which we give may make this still clearer. The top row represents an object of three simple colours, red, green, and blue-violet. The next three rows represent negatives of it obtained by photographing it through colour screens, which only allow the red, the green, and the blue-violet rays respectively to act. The next three represent the transparencies. In the last we have a side view of the three transparencies, and show diagrammatically a beam of white light passing through them


RED
GREEN
BLUE - VT
YELLOW
PINK
PINK
GREENISH-BLUE


Red rays thus—
Green rays thus-
Blue-violet rays thus-

and falling upon the screen beneath. It will be seen that the image on the screen is formed by rays of the same colour as originally proceeded from the object. The blue-violet, green, and red rays in the white light are indicated by a difference in their drawing.

Having thus shown in outline the principle of the process, we may point out that it has quite recently been worked out practically by Mr. Sanger Shepherd. We have to obtain three negatives of the scene to be depicted in colours, through blue-violet, green, and red screens respectively. Sir William Abney has worked out methods by which screens of the necessary degree of accuracy may be ensured, and Mr. Shepherd has made them to suit Cadett's Spectrum plate, and has put them upon the market. From these negatives prints are made by the carbon process on thin celluloid films.

In case any of our readers are not familiar with the process, we may point out that gelatine and potassium bichromate are exposed to light under the negative, and then placed in warm water. The light renders the gelatine insoluble. Where it has acted the gelatine remains; where it has not acted it dissolves away. Hence we have an image in which the shadows are represented by gelatine, the high lights by no gelatine (that is, by the bare celluloid only). If we dip such an image in dye, say in violet dye, the gelatine absorbs the dye and we have violet shadows and clear high lights.

In actual practice clear gelatine cannot be used, and so for convenience some containing silver bromide, similar to a dry plate emulsion, is used. This is bichromated, dried, and exposed under the three negatives. It is then "developed" in warm water, and finally placed in hypo to dissolve out the silver bromide, which will then have served its purpose. The three films are next immersed in dyes of the colours indicated above, viz., the film

Printed	under the	blue-violet	negative in	yellow	dye.
,,	,,	green	,,	pink	,,
,,	,,	red	,,	greenish-blue	,,

The three films are then carefully placed one on the top of the other, and mounted between glass. The result is a lantern slide in colour which can be shown in the ordinary single lantern.

Mr. Shepherd is now placing upon the market the colour screens through which the negatives are taken, the film upon which the prints are made, and the dyes for staining them when made. It will be seen that this places the process upon so sound a scientific basis that anyone with reasonable care and a knowledge of ordinary photography should have no difficulty in making slides in colour by the method.

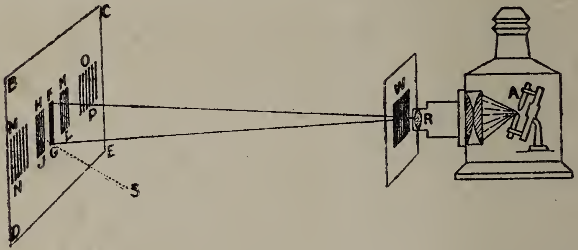
9.—*The Diffraction Grating Process.*

This is the latest modification of the three-colour process, and is the invention of Professor R. W. Wood, of Wisconsin University, Madison. It depends upon the use of what is known as a diffraction grating, the nature of which we will attempt to explain very briefly.

A diffraction grating is a piece of glass or metal ruled with an immense number of parallel and equidistant lines. Some of the coarser gratings have only a thousand or so lines to the inch, while fine gratings have been ruled by Professor Rowland at the John Hopkins University with from twenty to fifty thousand lines to the inch. In metal gratings the light is reflected from the metallic surface. In the case of glass it may be either reflected from the surface or transmitted through the glass itself.

In either case the results are similar. Let us suppose we have a lantern A (page 56) throwing a beam of light upon the screen B C D E. If we put an opaque slide with just a narrow slit of clear glass in it in the lantern we can, of course, obtain an image of the slit on the screen by means of the lantern lens as at F G. If now we hold a diffraction grating W between the slit and the screen it behaves somewhat as a prism would. The image of the slit still remains at F G, but on each side of it appear spectra as at H J, K L, M N, O P. The two spectra H J, K L, nearest to the central image, are referred to as being of "the first order," the next two M N, O P, as of "the second order," and so on. In all these spectra the violet end is nearest to the central image, and the red the farthest away.

The extent of diffraction depends upon the closeness of the rulings. This is an important factor, as will appear later on. Thus, if we had three slits projected upon the screen, and held in front of one a grating of 2,000 lines to the inch, in front of the next one of 2,400 lines to the inch, and in front of the third one of 2,750 lines to the inch, we should get some such result as is to be seen in the figure on page 57. The finer the lines the more the spectrum would be lengthened out, and the further would it be from the central image. With three gratings of the degrees of fineness given, which are those actually employed by Professor Wood, we should get spectra of the first order, occupying positions as shown. That is to say, the red with the coarsest, the green with the intermediate, and the violet with the finest ruling would all be at the same distance from the central image.



Now let us suppose that a hole were made in the screen, the eye placed behind it, and the lens R looked at through the grating. If the hole were made as at S (page 56) in the violet of the spectrum the whole of the lens R would appear as if filled with violet light. If the hole were made in the green it would appear filled with green light, if in the red with red light. Further, if the grating, instead of being ruled all over the glass, were only ruled over a portion of it, that portion would appear as a mass of the particular colour, and the rest of the space would appear black. The reason why the glass appears black where there is no ruling is that the eye when at S or, in fact, anywhere out of the axis of the arrangement, receives no light from a plain piece of glass with parallel sides, the ruling being necessary before any of the rays which otherwise go to make the image F G of the slit are diffracted.

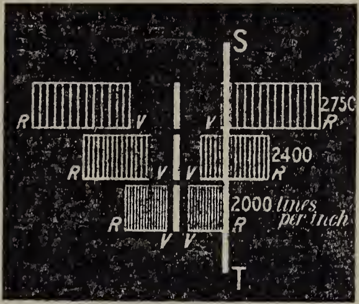
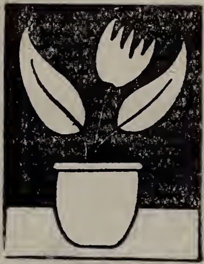


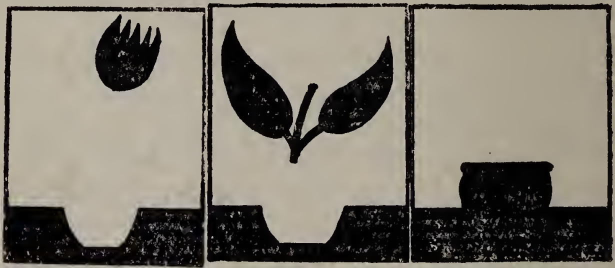
FIG. 2.

Hence, if we made a long vertical slit in the screen, as at S T (above), and passed the eye along it, the three lenses which were projecting the three images would appear to be filled with red, with green, and with blue-violet light respectively.

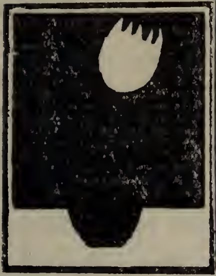
The ruled gratings can be copied by photography. A piece of glass is coated with bichromated gelatine, and exposed behind one to light, printed in fact, and may then be developed by washing in warm water—that is by what is practically the carbon process. They have also been made by the collodion process. Mr. Thorp has copied them in a most ingenious manner by "casting" in celluloid dissolved in acetone or amyl acetate.


Prof. Wood's example.

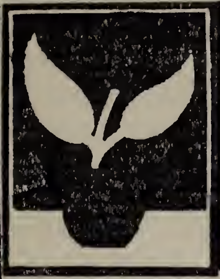
In order to make quite clear to those who have followed these chapters so far how these diffraction gratings have been applied to the three-colour process, we cannot do better than take Professor Wood's own illustration. Let us suppose we have a blue flower-pot standing on a white cloth. In it are green leaves and a red flower. The outline is shown in the margin. The background is black. From this three negatives are made through red, green, and blue-violet screens in a manner already described. They would have somewhat the appearance of the figures above.


Red Negative. *Green Negative.* *Blue Negative.*

From these negatives transparencies are made by any ordinary photographic process, which will then appear as follows:



Red Transparency.



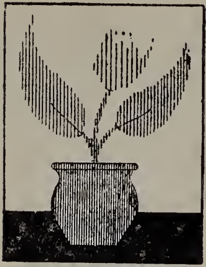
Green Transparency.

Blue Transparency.

A piece of glass is then taken, coated with bichromated gelatine, covered with a grating, say of 2,000 lines to the inch, and then with the transparency made from the red negative and exposed to light. In this "red" transparency the parts which were red in the original are represented by transparent parts; consequently where they fell the diffraction grating would print itself upon the sensitive surface beneath it.

If the process were stopped at this stage and the plate developed with warm water we should have a print from the transparency in which all the red portions of the original were represented by rulings, 2,000 to the inch. The half-tones of the transparency would be represented by feebler rulings. The opaque portions of the transparency would be rendered by clear glass.

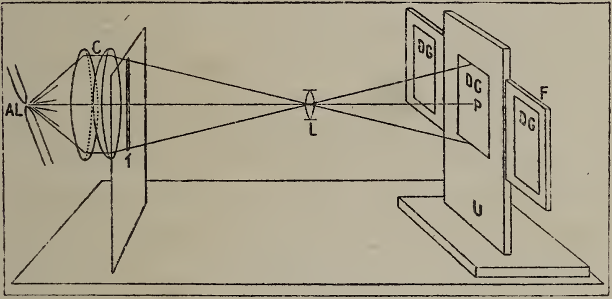
But if instead of developing the plate it is again exposed to light, but this time under the "green" transparency, and with a grating of 2,400 lines to the inch, we have on the same plate an image of the green parts of the object in rulings this distance apart. If, finally, it is exposed under the blue-violet transparency, with the 2,750 lines grating, the blue-violet parts of the image are impressed upon it in lines with this degree of spacing. The plate is then developed in warm water, and the result is suggested in the margin, where the spacing has been intentionally exaggerated.


The "Diffraction" Photograph.

Those parts of the original which were black will be reproduced on such a plate as clear class. The white parts will have all three sets of lines upon them. Compound colours in the same way will be made up by faint or vigorous images of two or more of the rulings.

The effects obtained when one set of lines is thus superposed upon another are said to be satisfactory in actual practice in most cases. It sometimes happens that they are not, and that one ruling coming above another interferes with it. This can only be referred to here, where the mere statement that such cases of interference have been met with must suffice.

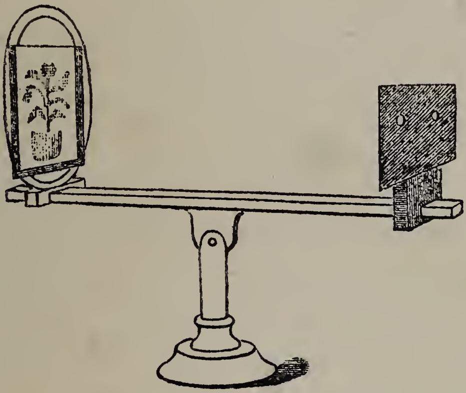
When such a plate impressed with the three images that we have described is placed in the position of the diffraction grating as shown on page 56, and viewed from an aperture in the screen placed as at S T (page 57), a moment's reflection will show us that the position of the eye is such that the parts with the coarsest ruling appear red, those with the intermediate appear green, those with the finest blue-violet. The background with no rulings at all will appear black. The cloth with all three rulings will appear red + green + blue-violet, that is white. In other words, the photograph would appear in its correct colour.



In practice it is not possible to get good pictures by quite so crude a plan as placing a glass grating between the transparency and the sensitive plate. A method which the figure will make plain is that generally adopted. The transparency is placed at T, lit by an arc lamp A L and condenser C. An image of the transparency is sharply focussed by means of the lens L upon the surface of the diffraction grating D G. The three gratings are placed in a frame at F, sliding through an upright U, so that each grating in succession may be brought into the position P, where it is immediately in front of the plate P, which is carried in a space provided for it in the upright. The first transparency being put in position, centred and focussed sharply on the first grating, the plate is exposed for a suitable length of time. A yellow glass between the arc lamp and the condenser, not shown in the figure, prevents any printing action from taking place while the adjustments are being made. Then the second transparency and the next grating are substituted, taking care that the second image falls upon the plate in perfect register with the first. Then the third transparency and grating are used, and finally the picture is developed.

To view these pictures, which are not only colourless when looked at in the ordinary manner, but are almost invisible, they must be suitably illuminated, and a peephole provided so that the eye can occupy the right place. The apparatus used by Professor Wood is a very simple one, and is shown on the next page. A stand provided with a metal plate and eyehole at one end carries at the other the diffraction photograph, and between them a lens for viewing purposes. The light for doing so must be a slit placed parallel with the lines on the gratings, or nearly so. A Welsbach lamp a good distance from the photograph is sufficiently near to this requirement to do very well, or the side view of the filament of an incandescent electric light will answer.

It was considered a shortcoming of the process at first that one eye only could be used for viewing the results. As a grating gives spectra each side of the central line, such colour photographs have been arranged by Professor Wood with two eyeholes, so that both eyes could be used, one seeing one spectrum and one the other. Mr. Ives has suggested putting the lines of the gratings horizontal instead of vertical. A movement of the eye along a line parallel with the rulings does not alter the colour, but movement at right angles does, so that by putting the lines horizontal it is possible to arrange instead of one eyehole a horizontal slit through which both eyes could look at the same time.



Perhaps it is in the reproduction of these photographs that the most interesting feature of all is to be found. As they consist simply of the presence or absence of furrows on the surface of transparent material, they may be copied by printing in contact on bichromated gelatine. The lines, although not actually differing in transparency, nevertheless impress themselves upon a sensitive surface placed beneath them and exposed to light. The cause of this is to be found in their very power of diffracting the light falling on them. Hence it is only necessary to expose the sensitive gelatine-coated glass beneath one of the pictures, wash it in warm water, and a copy is made. Every copy is a positive, no negative is required, since the lines and spaces (which alone constitute the picture) are there the same distance apart in original and copy.

10.—*Three-colour Photo-mechanical Prints.*

The last process with which we have to deal at any length is that alluded to above. Like those which have preceded it, the bases for the three prints are the three negatives taken through red, green, and blue-violet screens respectively. What has to be done is to print such negatives by some photo-mechanical process, using inks of suitable colours.

As these inks are to be laid one on top of the other on the white surface of a sheet of paper, the process is a subtraction and not an addition one—in fact, the state of things is very similar to that shown in the figure in Chapter 8 on page 52. The difference is that the screen at the bottom of the figure (represented by the white paper) is in contact with the transparencies (in this case the layers of coloured ink), and is viewed through them. Light, therefore, traverses each film of colour twice, once in going to the paper and once returning from it to the eye; hence the colours need not be so intense as in transparencies, where it only passes straight through once.

It might be thought that any process capable of giving prints in ink of any colour would be suitable for printing these negatives. There are certain difficulties, however.

The first process to be seriously tried was that known as "collotype." This may be described as a kind of lithography, in which a glass plate covered with bichromated gelatine printed under a negative takes the place of the stone bearing its drawing or transfer. The plate is kept wet, wet gelatine repelling the greasy ink employed. Only the parts where the light has rendered the gelatine insoluble take up the ink. The plate is accordingly rolled with a roller covered with thin lithographic or greasy ink, and then a piece of paper laid upon it. On removing the paper we find we have the exact reproduction in the ink of the image on the gelatine.

As the process works equally well irrespective in general of the particular colour of the ink employed, it would seem to be fitted for three-colour work. All that is necessary is to make three collotype plates from the three negatives, ink them up with yellow, pink, and greenish blue ink respectively, and print all three on one piece of paper. Those who do not understand why yellow, pink, and greenish-blue are the colours suggested, and not red, green, and blue-violet, are referred to the two chapters immediately preceding.

Unfortunately for the success of the process the actual amount of colour printed on the paper by each plate is continually varying. It is essential to a good result that there should be just the right amount of each, and in collotype this cannot be guaranteed. In fact, although some beautiful three-colour collotypes have been produced at one time or another, they have not been done commercially, and those shown have been picked here and there out of a number of prints. One in thirty or forty, we are told, is the proportion of good prints; that is, those in which the plates have deposited the colours in approximately correct proportions. This difficulty seems effectually to prevent collotype from becoming a successful means of working the three-colour process.

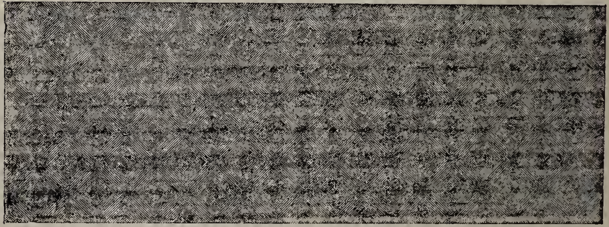
We are driven to photogravure and to photo-relief blocks, therefore, as the two remaining processes. Photogravure, the most beautiful of all photo-mechanical processes, has not received much attention from colour workers, because the output is essentially limited, and the process of printing very costly.

Photo-relief blocks such as are now used in most illustrated papers are prepared by the half-tone screen method. The printing surface is composed of minute dots, which stand up above the general level of the sheet of copper. The inking roller in the machine passes over them, and leaves on the surface of each dot some ink, which is transferred to the paper when this latter comes in contact with the block. Hence such blocks can be printed with ordinary type, behaving in exactly the same way. The printing face is, in fact, *in relief*. In photogravure the printing surface is in *intaglio* (sunk in).

The making of such a block from a photograph is an everyday occurrence in photo-engraving shops, and to make three such blocks from our three negatives would seem to present very few difficulties. It is not quite as simple as it seems, however, for a reason which an experiment will easily make plain.

Let the reader take two pieces of fine muslin, hold them up separately to the light, and look through them. The crossed threads will be clearly seen giving a regular and not obtrusive pattern. If the two pieces are superposed, it will be seen that the slightest movement of one on the other gives rise to the most extraordinary markings, which, if never noticed before, will greatly surprise the beholder. When the lines on both pieces absolutely coincide there will be none of them, but this is almost impossible to effect, and the slight difference between the two cause patterns like those of watered silk to appear.

Much the same sort of thing occurs if the regular ruling of one half-tone block be superposed on that of another. Patterns of the most aggressive character manifest themselves unless certain precautions are taken. We give below a block made simply from two such ruled screens placed together with the lines slightly out of parallel. The cross pattern need not be pointed out.



To get over this difficulty the blocks are made through a ruled screen in which all the lines run in the same direction, that is, from one-half of a "crossline" screen. Furthermore, the direction of the lines in the three blocks is changed so that they make an angle with one another of sixty degrees. That is, if the lines in the case of the first block are vertical, those of the next cross it at sixty degrees from the vertical, and those of the third at sixty degrees from the second. When this is done the "watering" effect is lost, and the dots do not look very different from those in an ordinary block.

The process is still far from being a perfect one in its practical details. The gradation of the three blocks must be very perfect to secure the best result; it must be alike in all three cases. The temptation to tamper with the process by means of handwork, a strong one, because of its ease as compared with the more legitimate one of finding out where the method itself is wrong and correcting it, is, we believe, responsible for many of the unhappy results shown as being "by the three-colour process." In spite of these it is one which is rapidly growing in favour, there are no insuperable theoretical difficulties in the way of producing a perfect or almost perfect result by its means, and as a method with a commercial future it is the best of all systems of photography in colours.

11.—*Other Three-colour Processes.*

In the case of the Joly process certain modifications have from time to time been devised. McDonough in the United States has suggested the employment of irregular colour screens instead of the parallel lines of Joly, but, as far as we are aware, specimens obtained by such means have not been shown, at any rate in this country. Still more recently Sczrepanik, an inventor who has at least had his full measure of publicity, has patented a process by which the lines of the Joly process are obtained by means of three successive exposures, using a stop of a particular shape with a colour screen and a single ruled screen with parallel, opaque and transparent, lines.

Then, again, in the matter of the photochromoscope there have been Barnard and Gowenlock's patents, resulting in the instrument known as the Kromaz. This is virtually a simplified form of photochromoscope. The colour screens as used by Ives are employed, but advantage is taken of a well-known optical principle to reduce the number of stereoscopic pairs of pictures required to get the colour effect from three to two.

The brain is capable of combining the effects produced when the two eyes see pictures differing in some respects, but alike in others. It is upon this principle that binocular vision itself is based. The pictures seen by the two eyes differ but very slightly by reason of their different standpoints. The result is we are conscious of but one image, although we realise at the same time that there is a difference in the two sensations that give rise to it. The consciousness of this difference is what we appreciate when we say we realise a stereoscopic effect. If the two images also differ in colour the eyes, or rather the brain, receive a compound sensation, and we perceive the object not as possessing two different colours but one, a compound of the two. Hence if with one eye a certain object presents one colour, and with the other it appears of the complementary colour, it gives us the same sensation as if it were white—this because the complementary of any one colour is that colour which added to it produces white.

In the Kromaz, therefore, we have two stereoscopic pairs, that is to say, four images. One of these is obtained through a blue-violet screen, one through a red screen, and two through green screens. This not only enables the whole record to be got easily upon a half-plate, but it very considerably simplifies the viewing apparatus. This only needs one mirror instead of two, which reduces its complication by half or even more. There are other differences between the two systems, but to these we need not refer, since they are mechanical alterations rather than modifications of the three-colour part of the procedure.

12.—*Conclusion.*

The various processes of photography in colours have now been summarised. Other modifications have been suggested from time to time. Some are merely different ways of attaining the same results, some simplify one or other of the processes, others add fresh complications. We have had in view all along typical methods rather than anything like an exhaustive survey which professed to allude to all. Any attempt to give working details for the benefit of those who want to take up one or other of the methods described we have regarded as outside the scope of this little book. We have not written with such a reader in view. Those who are ambitious, and desire to try their hands, must be prepared to go a great deal further into the theoretical side of the subject than we have done in this outline, must be also skilled photographers, possessed of perseverance, and willing to encounter failures with a light heart and a determination to do better.

Whether any of these methods can be truthfully said to solve the problem of "photography in natural colours" must depend on the meaning that is attached to that phrase. By suitably defining it, it may be said that undoubtedly they do afford means of accomplishing that desirable end. Without such a strained definition, and employing the term "photography in natural colours" in the sense in which it is used by that oft-quoted individual, "the man in the street," we should be inclined to say without hesitation that, not only is "photography in natural colours" still an impossible feat, but that we are as far from it as we were in the days of Daguerre, and likely to remain so. The beautiful processes of Ives and Lippmann, exquisite as are the results they yield in skilful hands, are makeshifts and no more. The public unquestionably means by "a photograph in natural colours" a photograph which, in addition to giving the image of its subject in monochrome, shall do so in pigment colours; in other words, a photograph which shall bear to the ordinary photographic print the same relationship that a painting does to a black and white sketch.

The interference colours of a Lippmann photograph, of course, do not comply with such a demand. The three-colour process in all its many modifications is hardly different, and it is not easy to see how it ever can be. The photograph in natural colours must get its colours by an accurate and automatic process, just as the photograph gets its outlines and perspective. To get its perspective untrue, the photograph must be tampered with, and in the absence of any evidence that this has been done the public assumes a photograph to be a truthful record, and in doing so is wise. With every three-colour process of which we have ever heard, not only are its results more often false than true, but we know when they are true that this truth, if not purely accidental, has been got not automatically, like the drawing given by the lens, but by the active interference of the photographer in adjusting and balancing one colour with another till he got a result that pleased him.

We have not been at the trouble to point out all this for the purpose of decrying either the work of Professor Lippmann, or that of Mr. Ives and his followers. So far from that, we think the recognition by the latter of the truth that it is upon the lines of the three-colour process, and as far as we can see of that only, that there is any prospect of success to an inventor in the shape of a practical, workable process, is in every way a testimony to their insight and ability. They have taken the line of least resistance.

The reason for going into the question has been rather to set forth what basis there is for the belief we hold, viz., that not only is "photography in natural colours" not yet attained, but that there is no indication as to any direction in which we may look for its coming, and that in short the odds against any such process ever being worked out are so great as should suffice to discourage the most sanguine investigator who ever lived.

"Photography in natural colours" not only never has been accomplished, but we believe never will be.

Natural Colour Photography.

SANGER SHEPHERD PROCESS.

A simple, inexpensive, and reliable process, based upon sound scientific principles, for obtaining photographs of any object in its natural colours, faithfully reproducing every shade and tint, in a manner absolutely satisfying to the eye.

Circulars on application.

Complete Lantern-size Developing and Printing Outfit, containing all necessary apparatus—trays, special printing frames, clips, plates, films, solutions and materials for developing the negatives, printing the separate sensation transparencies and mounting, together with examples of a triple print in various stages	£4 4 0

* * * * * *

SANGER SHEPHERD & CO.,

Manufacturers of Scientific Apparatus,
Light Filters for Orthochromatic Work,
Three Colour Filters

(Medal Royal Photographic Society, 1899),

APPARATUS AND MATERIALS FOR PROCESS WORK,

AND

Every requisite for the Photography of Colour.

Descriptive Catalogue post free on receipt of three penny stamps.

◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

**FACTORY AND OFFICES: 5, 6 & 7, GRAY'S INN PASSAGE, RED LION STREET,
HOLBORN, LONDON, W.**

Photography in Natural Colours

Adaptable to any Camera.

☛ Brought within the reach of all by the KROMAZ PROCESS.

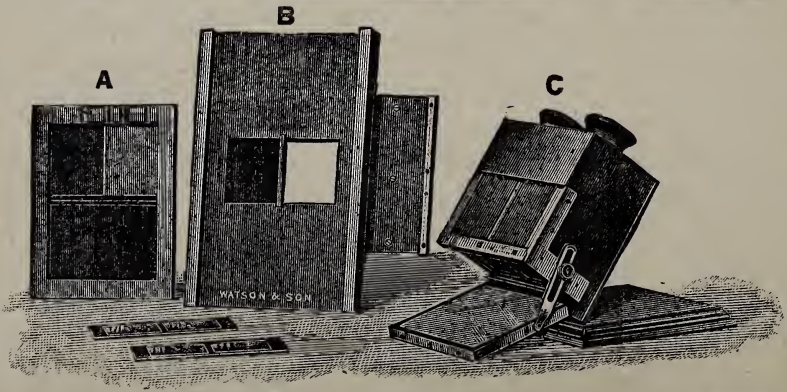
Gives

Stereoscopic

Effects in

Colour.

Two Exposures only required for Half-plate Cameras.



PRICES.

Kromaz Repeating Holder B, with set of Colour Screens A, for taking purposes, £2 2s.

Kromaz Stereoscope C for viewing, £2 10s.

Set of Mirrors to give Stereoscopic Images using one Lens, 12s. 6d.

Full descriptive pamphlet free on application to

W. WATSON & SONS, 313, High Holborn, W.C.

(Opticians to Her Majesty's Government.)

Branches—16, FORREST ROAD, EDINBURGH. 78, SWANSTON STREET, MELBOURNE.

Factories—9, 10, 11, 16, and 17, FULWOOD'S RENTS, HOLBORN. Established 1837.

THE

SPECTRUM

PLATE

AND

LIGHT FILTERS

Revolutionising Photography.

Extracts from letters just received: *April, 1900.*

No. 1.

"A number of gentlemen well known in **Philadelphia** photographic circles . . . have made thorough tests of all the photographic plates (colour sensititive) now on the market, and have reached the conclusion that the Cadett 'Spectrum' **has no equal.**"

No. 2. From **Boston.**

"I have just ordered by the . . . . six gross of the Cadett 'Spectrum' plates for photomicrographic work. I find your plates admirably adapted for this purpose."

No. 3. From **Berlin.**

"The . . . Department of . . . . . . intends to use in their three-colour printings your so well-known and appreciated Spectrum' plates and the light filters adjusted to them."

No. 4. From **Mr. C. Churchill.**

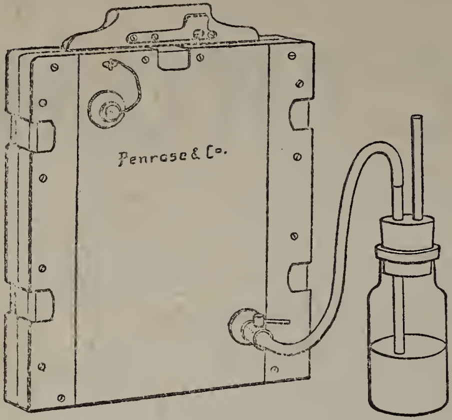
"It may interest you to learn that at the last South London Exhibition I obtained the first medal given under the Edwards Memorial Scheme for rendering colours in correct visual monotone, the subject being an oil painting of a vivid sunset, the property of Mr. E. J. Wall. The plate used was the 'Spectrum,' with your filter."

Write for Booklet, "ORTHOCHROMATIC PHOTOGRAPHY," simplified by James Cadett. Gratis. Post free.

SOLE MANUFACTURERS—

CADETT & NEALL, LTD., ASHTEAD, SURREY,

Dry Plate and Paper Manufacturers.



PENROSE'S PATENT DARK SLIDE, WITH MERCURY RESERVOIR FOR THE LIPPMANN PROCESS.

Everything for . . Colour Work

by Photographic Processes.

Sanger Shepherd Measured Colour Filters,
Carbutt's Colour Screens,
Screen Holders,
Safe Light Lantern,
Colour Cells,
Dark Slides for Lippmann Process,
Special Inks for Three-colour Printing,
Spectroscopes, Prisms,
Dyes, etc.,

Supplied by

PENROSE & CO., 8 and 8a, UPPER BAKER STREET, LLOYD SQUARE, LONDON, W.C.

PARIS: 44, Notre Dame des Champs. SYDNEY: Safe Deposit Buildings.

UNIFORM WITH THIS VOLUME,

AND FORMING THE SERIES KNOWN AS

"PHOTOGRAPHY" BOOKSHELF.

No. 1.—PHOTOGRAPHY FOR ALL. By W. Jerome Harrison.
No. 2.—THE GUM-BICHROMATE PROCESS. By W. J. Warren.
No. 3.—THE HAND CAMERA. By Walter D. Welford.
No. 4.—THE PLATINOTYPE PROCESS. By W. J. Warren.

Price 1/- each nett from all Booksellers, or post free 1/3 from the Publishers,

ILIFFE, SONS & STURMEY LTD.,
3, St. Bride Street, Ludgate Circus, London, E.C.

85-B8162

12/84
ILXY
8413

GETTY CENTER LIBRARY CONS
NH 810 B35 1900 BKS
c. 1 Bayley, R. Child, 18
Photography in colours,

3 3125 00275 2562